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Exergy analysis for a proposed binary geothermal power plant in Nisyros Island, Greece

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ABSTRACT

The exergy analysis method constitutes an alternative but very important technique for the evaluation of the utilization level of thermal plants as well for the comparison of different conversion processes. The loss of exergy provides a figure of merit for the inefficiencies of a process and a measure of the quality of the different forms of energy in relation to given environmental conditions. In this paper, data from an experimental geothermal drill in the Greek Island of Nisyros, located in the south of the Aegean Sea, have been used in order to estimate the maximum available work and the efficiency of a potential power plant. Different methods for estimating the exergy term are used and several types of conversion efficiencies have been calculated in order to obtain a more complemented view of the analysis. Overall, a system exergetic efficiency of 41% and a thermal one of 12.8% have been resulted supporting technical feasibility of the proposed geothermal plant.

1. Introduction

The increased concern about the world's limited energy resources has alerted many authorities involved to reconsider their energy policies and take drastic measures in minimizing energy consumption and wasted energy and in utilizing alternative energy sources, such as renewable energy sources (RES) (Lior, 2008; Bataineh and Dalalah, 2013; Izutsu et al., 2012). The goal that has been set focuses on the optimization of energy conversion devices/processes and on the development of new techniques to better utilize the existing limited energy resources (Ali et al., 2012; Raslavičius and Bazaras, 2010; Li et al., 2013). RES offer a great potential when partial or complete (if and where this is possible) replacement of conventional fossil fuel is concerned; however, most forms of RES present problems with high investment costs and low energy density (Hadjipaschalis et al., 2009). Geothermal energy, is not at all dependent on weather conditions, therefore it allows a constant energy flux (Köse, 2005). The use of geothermal energy as a possible source for electricity generation, however, is limited to countries with high enthalpy geothermal sources (Goldstein et al., 2017). The exploitation of geothermal sources may also cause a range of environmental problems depending on the location, on the technology used and on the legal framework for the proper exploitation (Kömürcü and Akpinar, 2009; Al-Dabbas, 2009).

Geothermics, or energetic exploitation of hydrothermal resources, utilizes hot water or steam which can be found in porous or fissured rocks in the Earth's crust. Commercial geothermal electricity generation started in Lardarello, Tuscany, Italy in 1913 with an installed electric capacity of 250 kW (Barbier, 1997). This is one of the rare locations where superheated steam is available from geothermal wells. The first power plant based on geothermal hot water has been in operation in Wairakei, New Zealand since 1958 (Barbier, 1997). Today, the installed electric capacity amounts to some 11 GW worldwide (Holm et al., 2010). The leading producers are the USA, Philippines, Indonesia, Italy and Mexico (Holm et al., 2010). Due to proper geological conditions, Greece has many important geothermal resources (of all three categories – low, medium and high temperature) in relatively economic depths (100–1500 m). The research for geothermal exploration in Greece started in 1971 by the Institute of Geology and Mineral Exploration (I.G.M.E.) and up to 1979 the research program covered only areas considered to contain high enthalpy resources. The most important geothermal fields have been discovered in Milos and Nisyros islands (Institute of Geology and Mineral Exploration (I.G.M.E.), 1981; Public Power Corporation of Greece, Merz – Dal Geothermal Consultants, 1993; Greek Institute of Geology and Mineral Exploration

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Nomenclature

Subscripts

0	Atmospheric (ambient) conditions
fg	Geothermal fluid
i	Initial conditions
l	Liquid
out	Intermediate state
s_t	Turbine
s_v	Pump
u	Utilization
v	Vapor (steam)

Greek Symbols

η	Thermal efficiency
ζ	Exergy efficiency
cp	Specific heat capacity (constant pressure) (kJ/kgK)
$C_p^{\tilde{h}}$	Mean molar isobaric specific heat for evaluating enthalpy changes (kJ/kgK)
$C_p^{\tilde{s}}$	Mean molar isobaric specific heat for evaluating enthalpy changes (kJ/kgK)
$C_p^{\tilde{E}}$	Mean molar isobaric specific heat for evaluating exergy changes (kJ/kgK)
$\dot{E}$	Exergy flow (kJ/s or kW)
E	Total exergy (kJ)
e	Specific exergy (kJ/kg)
h	Enthalpy (kJ/kg)
m	Mass (kg)
$\dot{m}$	Mass flow rate (kg/s)
p	Pressure (bar)
s	Entropy (kJ/kgK)
T	Temperature (°C or K)
W	Power, work (kJ)
P, $\dot{W}$	Power, work rate (kJ/hr)
x	Mass fraction
0	Atmospheric (ambient) conditions
fg	Geothermal fluid
i	Initial conditions
l	Liquid
out	Intermediate state
st	Turbine
sv	Pump
u	Utilization
v	Vapor (steam)
η	Thermal efficiency
ζ	Exergy efficiency

(I.G.M.E.), 1999, 1985; Mendrinos et al., 2010).

Exergy analysis is a valuable tool for this performance evaluation (Madhawa Hettiarachchi et al., 2007; Heberle and Brüggemann, 2010; Guzović et al., 2010; Akpinar and Hepbasli, 2007; Dağdaş et al., 2005; Keçebaş, 2011). Due to the relatively low temperatures of geothermal fluids and thus, the low energy efficiencies and the small difference between energy efficiencies of a well and a poorly performing geothermal power plant, it is necessary that the comparisons made to be based on the quality of the geothermal resources (Kanoglu, 2002; Yuan and Michaelides, 1993). Exergy analysis is a useful methodological tool that accounts for the system's inefficiency in terms of exergy destruction, i.e., the degradation of the system's ability to perform work with respect to its surroundings (Dincer and Rosen, 2006). The concept of exergy was first used to analyze a geothermal power plant by Badvarsson and Eggers (Bodvarsson and Eggers, 1972), who compared the performances of single and double flash cycles based on a reservoir water temperature of 250 °C and a sink condition of 40 °C; gave exergetic efficiencies of 38.7% and 49%, respectively, assuming 65% mechanical efficiency (Lee, 2001). DiDippo (DiPippo, 1994) investigated the second law assessment of binary plants generating power from low-temperature geothermal fluids. The results show that binary plants can operate with very high second law or exergetic efficiencies even when the motive fluids are low-temperature and low-exergy. Exergetic efficiencies of 40% or greater have been achieved in certain plants with geofluids having specific exergies of 200 kJ/kg or lower. During the past decades numerous studies (Kanoglu and Cengel, 1999a; Kanoglu and Cengel, 1999b; Barbier, 2002; Golove and Schipper, 1997; Gunerhan et al., 2001; Hepbasli, 2003; Esen et al., 2007; Koroneos and Nanaki, 2017; Ozgener et al., 2005a; Ozgener et al., 2005b; Ozgener and Ozgener, 2009; Yari, 2010) have been undertaken for geothermal systems to perform a large range of investigations from system basics to system energy and exergy analyses. Nonetheless it is noted, that there are few studies regarding performance evaluations and optimization techniques for geothermal power plants and reservoirs on a worldwide scale (Yuan and Michaelides, 1993; Kanoglu and Cengel, 1999b; Kanoglu et al., 1998; Cerci, 2003; Paloso and Mohanty, 1993; Subbiah and Natarejen, 1988). Notwithstanding there are many studies concerning geothermal fields located in southern Aegean Sea (Mendrinos et al., 2010; Marini et al., 1993; Lagios and Apostolopoulos, 1995; Brombach et al., 2003), published research dealing with geothermal power plants in that area is scarce.

The objective of this work to is to investigate the technical feasibility of constructing a 2 MW commercial geothermal power plant in Nisyros island, thus exploiting one of the most powerful geothermal fields of the Mediterranean sea. Given that the island of Nisyros has significant geothermal energy fields the operation of a geothermal plant is of great significance. Due to legal inefficiencies, the exploitation of this renewable energy source remains at very low levels. Thus the research on the development of a low enthalpy geothermal field is investigated as a very essential investment. The building of small geothermal power plants to supply mini-grid power in remote locations with geothermal resources, has proved to be very important. Data from an experimental geothermal drill in Nisyros (Institute of Geology and Mineral Exploration (I.G.M.E.), 1981; Public Power Corporation of Greece, Merz – Dal Geothermal Consultants, 1993; Greek Institute of Geology and Mineral Exploration (I.G.M.E.), 1999, 1985) are used in this work in order to estimate the maximum available work and the efficiency of a potential power plant. In order to obtain a more complemented view of the analysis, different methods for estimating the exergy term are used and several types of conversion efficiencies are calculated.

2. Characteristics of geothermal well Nis-2 on Nisyros Island

Flow tests were carried out in 1981, 1983 and 1985 at a geothermal field in Nisyros (Institute of Geology and Mineral Exploration (I.G.M.E.), 1981; Public Power Corporation of Greece, Merz – Dal Geothermal Consultants, 1993; Greek Institute of Geology and Mineral Exploration (I.G.M.E.), 1999, 1985). Carriers of these tests were Public Power Corporation of Greece and I.G.M.E. The tests were an attempt to evaluate the production characteristics and the composition of fluids from the Nis-2 well. The well was drilled slightly in 1985 and was subjected to flow tests for three months. From the collected data (Institute of Geology and Mineral Exploration (I.G.M.E.), 1981; Public Power Corporation of Greece, Merz – Dal Geothermal Consultants, 1993; Greek Institute of Geology and Mineral Exploration (I.G.M.E.), 1999, 1985), presented below, Public Power Corporation and I.G.M.E. estimated that the field under study could supply a 2 MWe geothermal